# Geology of the Spruce Pine District Avery, Mitchell, and Yancey Counties North Carolina

GEOLOGICAL SURVEY BULLETIN 1122-A

Prepared in cooperation with the Mineral Resources Division of the North Carolina Department of Conservation and Development





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By DONALD A. BROBST

CONTRIBUTIONS TO ECONOMIC GEOLOGY

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## UNITED STATES DEPARTMENT OF THE INTERIOR STEWART L. UDALL, Secretary

GEOLOGICAL SURVEY

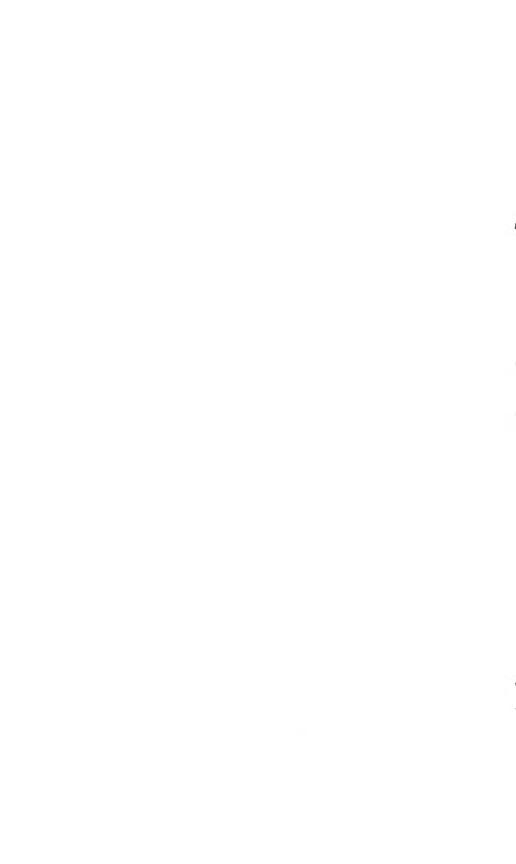
Thomas B. Nolan, Director

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### CONTRIBUTIONS TO ECONOMIC GEOLOGY

### GEOLOGY OF THE SPRUCE PINE DISTRICT, AVERY, MITCHELL, AND YANCEY COUNTIES, NORTH CAROLINA

### BY DONALD A. BROBST

### ABSTRACT

The Spruce Pine pegmatite district, a northeastward-trending belt 25 miles long and 10 miles wide, lies in parts of Avery, Mitchell, and Yancey Counties in the Blue Ridge Province of western North Carolina. The most abundant rocks in the district are interlayered mica and amphibole gneisses and schists, all of which are believed to be of Precambrian age. These rocks are cut by small bodies of dunite and associated rocks of Precambrian(?) age, large bodies of alaskite and associated pegmatite of early Paleozoic age, and basaltic and diabasic dikes and sills of Triassic(?) age. The rocks of the district have been weathered to saprolite that is locally 50 feet thick.

The major structure in the area is a southwestward-plunging asymmetrical synclinorium that has its steeper limb on the northwest side.

Feldspar, muscovite as sheet and scrap (ground) mica, and kaolin from the alaskite and associated pegmatite account for over 90 percent of the total mineral production of the district. Amounts of other pegmatite minerals, including quartz, beryl, columbite-tantalite, rare-earth and uranium minerals are an extremely small part of the mineral resources. Actual or potential products from other rocks are olivine, vermiculite, asbestos, talc, chromium and nickel, soapstone, mica schist, garnet, kyanite, dolomite marble, and construction materials.

### INTRODUCTION

The Spruce Pine pegmatite district, the largest domestic source of feldspar and sheet mica, lies in parts of Avery, Mitchell, and Yancey Counties in the Blue Ridge province of western North Carolina. The pegmatites have been mined in a northeastward-trending belt 25 miles long and 10 miles wide near the intersection of the 36th parallel of north latitude and the 82d meridian of west longitude (fig. 2). The district is shown on the following 7½ minute topographic sheets prepared by the U.S. Geological Survey for the Tennessee Valley Authority: Bakersville and Carvers Gap, N.C.-Tenn., and Burnsville, Celo Black Brothers, Linville Falls, Micaville, Mount Mitchell, Newland, Spruce Pine, and Wood Mountain, N.C.

Spruce Pine, a town of 2,200 people along the North Toe River, is the commercial center of the district. Other important towns include Bakersville, Burnsville, and Newland. The Carolina, Clinchfield, and Ohio Railroad crosses the district along the Toe River Valley and connects with the Southern Railway at Johnson City, Tenn., and Marion, N.C. The district is accessible by paved highway—U.S. Highway 19E, and State Highways 26, 80, 197, and 261. These are joined by a network of paved or gravelled secondary roads and temporary logging and mining roads.

### FIELDWORK AND ACKNOWLEDGMENTS

Mapping was done by the U.S. Geological Survey in cooperation with the Mineral Resources Division of the North Carolina Department of Conservation and Development to determine the geologic features of this important pegmatite district. The work was done under the general supervision of L. R. Page and R. A. Laurence. Dr. J. L. Stuckey, State geologist for North Carolina, helped plan the work.

The geologic mapping was done at a scale of 1:12,000 by pace and compass methods between 1940 and 1953 by the geologists listed below. Numbers in parentheses following the authors named below indicate areas shown on (fig. 1) mapped by each geologist.

The mapping was begun in 1940 by J. M. Parker, III (1), and continued in 1941 by J. C. Olson (2), J. J. Page (3), and Parker. In 1947, Parker resumed the work. In 1948, mapping was continued under the direction of Parker with the assistance of D. A. Brobst (4), H. S. Johnson, Jr. (5), J. L. Kulp (6), and J. A. Redden (7). During the field seasons of 1948 to 1953, the field party was directed by J. L. Kulp with assistance of D. A. Brobst from 1949 to 1953, H. S. Johnson, Jr., in 1949, D. F. Beaumont (8) in 1950, D. R. Carr (9) in 1951, B. F. Sheldon (10) in 1951, F. D. Eckelmann (11) in 1951 and 1952, and R. K. Robbins (12) in 1952. The geologic map (pl. 1) was compiled by D. A. Brobst.

Mapping and economic studies were aided by the cooperation of miners, mine and mill operators, and local residents who freely supplied information about earlier operations, inaccessible workings, and mining and milling practices.

### PREVIOUS WORK

General geologic mapping on a small scale (1:125,000) in the Spruce Pine district and surrounding parts of the southern Appalachians was done by Keith (1903, 1905, 1907). No further areal studies were made in the district until 1940 when the cooperative work between the state and Federal geological surveys was begun. During the years of World War II, many of the pegmatites were

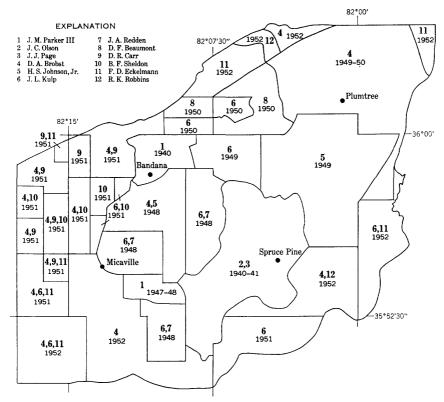


FIGURE 1.—Index to geologic mapping in the Spruce Pine district, North Carolina.

studied in detail. The first results of this work were described by Olson (1944) and subsequent progress reports on the work in parts of the district by Parker (1953) and Kulp and Brobst (1956).

Many publications describing mines and various aspects of the economic geology of the Spruce Pine district are included in the list of references cited.

### GENERAL AND HISTORICAL GEOLOGY

The Spruce Pine district is just west of the axis of the Appalachian geosyncline in the complexly folded core of gneisses, schists, and granites that make up the metamorphic and plutonic belt as described by King (1950). The belt lies between the western boundary of North Carolina and the western edge of the Carolina slate belt (fig. 2). This part of the geosyncline has been distorted by multiple and complex crustal movements with associated igneous activity. Bodies of dunite and associated rocks are widely distributed along the west flank of the geosyncline from New Jersey to Alabama.

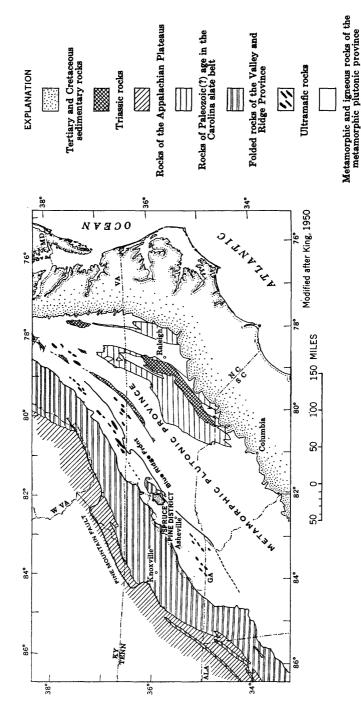


Figure 2.—Regional geology of North Carolina and adjacent areas.

The most abundant rocks of the Spruce Pine district consist of a sequence of mica and amphibole gneisses and schists, including small quantities of dolomite marble, all of which are regarded to be of Precambrian age (pl. 1). Age determinations by the potassium-argon method done by Carr and Kulp (1957, p. 782) complement the field evidence. These rocks successively have been invaded by small bodies of dunite and associated rocks of Precambrian(?) age, large bodies of alaskite and associated pegmatite of early Paleozoic age, possibly of Late Ordovician or Early Silurian age (Eckelmann and Kulp, 1957, p. 1122–1125), and essentially unaltered basaltic and diabasic dikes and skills of Triassic(?) age. The rocks of the district have been weathered to saprolite as much as 50 feet thick at some places. Weathering has altered some alaskite and pegmatite to commercial deposits of kaolin.

Other recent papers dealing with the rocks and geologic history in the Spruce Pine district and environs are by Eckelmann and Kulp (1956), Kulp and Poldervaart (1956), and Wilcox and Poldervaart (1958).

### TOPOGRAPHY AND DRAINAGE

The Blue Ridge province in the Spruce Pine district is characterized by a densely wooded, rugged topography. Many mountains rise above the rounded or flat-topped hills near the entrenched and meandering master streams. The master streams are the North and South Toe Rivers which join at Kona to form the Toe River. The valleys of these streams generally are narrow, but locally they widen out to 1/4 to 1/2 mile and are floored by a thin layer of alluvium. The valleys of the tributary streams are generally V-shaped and steepwalled; cliffs and waterfalls are common. Landslide scars and associated fans of debris are conspicuous in many places. The relief is great throughout most of the area and is greatest in the southwest and northeast parts of the district where the mountain summits and the valley-floor of the nearest master stream may differ in altitude by as much as 2,000 feet in a mile. The highest part of the area is the crest of the Black Range, about altitude 6,600 feet, in the southwestern part of the district. The lowest altitudes are along the Toe River, 2,340 feet at Kona and about 2,100 feet at Green Mountain. where the river flows northwest out of the district.

### METAMORPHIC ROCKS

The metamorphic rocks of the Spruce Pine district consist principally of an interlayered sequence of mica gneiss and schist, amphibole gneiss and schist, and a few beds of dolomite marble, all of Precambrian age. All the micaceous and amphibolitic rocks are inter-

layered. Each layer of rocks generally differs in composition from the adjacent layers. Individual layers range in thickness from less than 1 inch to as much as several tens of feet, but only rarely does an outcrop exposing a 10-foot stratigraphic sequence include layers of only one kind of rock. Contacts between mineralogically different layers are sharp.

The units of mica gneiss, mica schist, and amphibole gneiss and schist shown on the map are designated for the most abundant rock type, because within each major mappable unit, rocks of different composition are interlayered on such a small scale. The transition from one mapped unit to another, normal to layering, is accomplished by the gradual increase in number of rock layers characteristic of the adjacent mapped unit. Transitions parallel to layering also occur, especially between units of mica gneiss and mica schist, as seen north of Plumtree and on Pine Ridge, north of Buck Hill Mountain, both in Avery County. The contacts between the mapped units are located only approximately in most places because of the transition zones between the units and the lack of outcrops over much of this forested country. Outcrops are abundant only along the stream courses and in road and railroad cuts. The soil characteristics of each group of rocks, described below, are very helpful for mapping in areas where outcrops are scarce.

Foliation generally is conspicuous in all of the rocks because of the alinement of platy or needle-shaped crystals. The foliation is parallel to the compositional layers, regardless of folding of the rocks.

Keith (1903, 1905, 1907) mapped the mica gneiss and schist and the dolomite marble in this district as the Carolina gneiss, which he regarded as having originated from the metamorphism of sedimentary rocks in Precambrian time. He mapped the amphibole gneiss and schist as the Roan gneiss, believing it to be of igneous origin and to have been intruded into the Carolina gneiss in Precambrian time.

The terms "Carolina gneiss" and "Roan gneiss" have been used widely in the southeastern United States by Keith and later geologists for micaceous and amphibolitic metamorphic rocks, respectively. The type locality for each formation is only vaguely defined. The stratigraphic equivalence of all the rocks mapped as Carolina and Roan in the Southeast is questionable. The exclusively intrusive origin of all of the so-called Roan gneiss is also questionable, and the amphibolitic rocks probably are of diverse origins. Many problems of Keith's Carolina and Roan gneisses remain to be solved.

In this report, I prefer not to apply any formation names to the metamorphic rocks. The use of old formation names would perpet-

uate the confusion and the terms "Carolina gneiss" and "Roan gneiss" are hereby abandoned; the use of new names could add to the confusion. It seems best at this time to use mineralogic names for the rocks in this district.

### MICA GNEISS

The layers of mica gneiss are bluish or brownish gray on fresh outcrops and tan to rusty brown on weathered outcrops. The individual layers have a homogeneous appearance because the component minerals generally are distributed evenly. The chief minerals of the mica gneisses, and the modal range of these minerals in 51 samples of common varieties, are oligoclase (35 to 60 percent), quartz (15 to 35 percent), biotite (10 to 25 percent), and muscovite (trace to 25 percent). Garnet, epidote, staurolite, kyanite, and orthoclase are more than 5 percent of some layers. Mica gneisses and schists containing as much as 40 percent blue kyanite are abundant in the western part of the district in a belt about 2 miles wide extending from Celo Knob in the south to Pigpen Bluff in the north. Included with the rocks of this group are some layers in which quartz constitutes up to 93 percent of the rocks. The grain size rarely exceeds 1 mm. The mica gneiss weathers to brown plastic soil that contains small grains of quartz and tiny flakes of silvery-white hydromica.

### MICA SCHIST

The layers of mica schist are bluish to brownish gray on weathered outcrops. The chief minerals of the mica schists and their modal ranges (as determined in 14 samples of common rock types) are oligoclase (10 to 60 percent), quartz (2 to 60 percent), muscovite (2 to 35 percent), and biotite (5 to 25 percent). Muscovite generally predominates over biotite. Garnet, in the range of 0 to 20 percent, is more common in mica schists than in mica gneisses. Epidote, kyanite, and staurolite exceed 5 percent in some layers of mica schist. Some layers contain scattered pods of quartz and plagioclase separated by thin streaks of mica. Mica schist generally is coarser-grained than mica gneiss, but the average grain size rarely exceeds 5 mm. The schist weathers to brown or reddish brown soil containing sand-sized grains of quartz and plagioclase and residual pods of quartz and feldspar coated with mica. The ground may be littered with crystals of kyanite and garnet where these minerals are abundant in the hedrock.

### AMPHIBOLE GNEISS AND SCHIST

The amphibole gneisses and schists generally are gray green to dark greenish black on fresh outcrops, depending on the relative abundance of light and dark minerals. Weathered outcrops are rusty brown

or red. The unit has many kinds of layered amphibole gneisses and schists; the most common types contain hornblende (50 to 80 percent), oligoclase or andesine (5 to 25 percent) and quartz (trace to 25 percent). Less common rock types contain actinolite, anthopyllite (?), garnet, diopside, epidote, zoisite, chlorite, and biotite in amounts greater than 5 percent. Quartz forms as much as 50 percent in some layers of the less common rock types. In rocks with both biotite and amphibole, the rock was assigned to the amphibole unit if it contained 5 percent or more amphibole, otherwise it was assigned to one of the types of micaceous rocks. Plagioclase, quartz, or garnet, alone or in combination, form elongate lenses of small crystals about half an inch thick in some layers. Garnet rarely forms metacrysts, but some grains are as much as half an inch in diameter. Staurolite was found in a garnet-rich amphibole rock from upper Blue Rock Branch. The grain size of the most common rocks generally ranges from 0.1 mm to 5 mm. The amphibole rocks have a tendency to break off in slabs. The soil developed from these rocks is generally dark red to reddish brown and is the most plastic in the area. This soil is easily distinguished from that derived from the mica rocks by its deeper red color and by the general lack of flakes of hydromica and pods of feldspar and quartz so common in the soils derived from the mica rocks.

### DOLOMITE MARBLE

White crystalline marble, composed of over 99 percent dolomite as grains ½ to ½ inch across, crops out in two beds about 10 and 40 feet thick along the Carolina, Clinchfield, and Ohio Railroad, 1 mile south of the junction of Roses Branch with the Toe River. The beds are separated by a sequence of mica gneisses 15 to 20 feet thick. The beds can be traced northeastward along strike about 2,000 feet. Marble has not been found to the southwest. The dolomite marble is cut by pegmatite and is only slightly altered. Actinolite and diopside have formed in the marble near the contacts with the pegmatite.

### **IGNEOUS ROCKS**

### DUNITE AND ASSOCIATED ROCKS

Thirty-three bodies of dunite and associated soapstone were mapped in the district. These rocks are widely distributed throughout the district, but in the western part there is the suggestion of distribution in a broad arc extending from Sevenmile Ridge in the south, through the Newdale area, to the Bandana area in the north.

Most of the bodies are less than 2,000 feet in the longest exposed dimension. Contacts with enclosing metamorphic rocks are sharp,

although the outer edges of the dunites generally are sheared and altered. The bodies of dunite are cut and metamorphosed by later pegmatite (Kulp and Brobst, 1954).

The dunite is made up primarily of forsterite (a 1.656, \$\beta\$ 1.668, γ 1.690, suggesting a magnesium: iron ratio of about 90:10) with minor amounts of antigorite, enstatite, talc, phlogopite, vermiculite, anthophyllite, chlorite, chromite, and magnetite. These less abundant minerals are commonly arranged in irregular zones roughly parallel to the contact with the country rock. The common zones from the contact with the wall rock inward include (a) talc-anthophyllite-serpentine fringe with vermiculite, (b) serpentized (antigoritized) dunite, and (c) a relatively granular olivine core, in which some grains may have serpentine rims. Accessory magnetite and chromite are generally well disseminated throughout the mass. Hunter (1941) presented an excellent series of photomicrographs illustrating the progressive alteration from relatively fresh to completely altered olivine. In his paper, petrographic analysis of the olivine core of the body at Frank shows the composition to be 70 to 80 percent olivine, 10 to 15 percent ferruginous enstatite, 5 percent chlorite, less than 1 percent chromite, and minor quantities of antigorite and talc. This appears to be typical of the composition of the essentially unaltered cores of the major dunite bodies of the district.

The cores of the dunite bodies are generally undeformed, although some evidence of deformation—shear planes and slickensided surfaces—may appear in the outer zones and extend part way into the core. The olivine is granulated and the interstitial spaces are filled by antigorite. Amphibole also may be present.

Soapstone is associated with all the dunite bodies, and many of the ultramafic bodies have been altered wholly to soapstone. The bodies containing the most soapstone are those near Hughes, in Soapstone Branch, along Grassy Creek, along Crabtree Creek, and near Green Mountain Gap.

The mineral composition of the soapstone is varied, but the chief constituents generally include tale, amphibole, chrysotile, and chlorite. Rosettes of tale are especially abundant in the body on Soapstone Branch. Feathery textures are the rule in these rocks.

The dunite and soapstone bodies weather to a dark-brown soil on which vegetation is scarce. Spheroidal and septarian weathering patterns are common and especially well displayed in road cuts through the Mine Branch body along State route 80 just north of Newdale. The talcose soapstone bodies are resistant to weathering and stand as mounds 10 to 25 feet high.

A small body of fresh black pyroxenite (not shown on the map) was found at the J. W. Autrey mine 1 mile southeast of Burnsville.

### ALASKITE AND ASSOCIATED PEGMATITES

The silica-rich igneous rocks that have invaded rocks formerly called the Roan and Carolina gneiss and the dunite were first called granite and pegmatite by Keith (1903, 1905, 1907), who mapped them as part of the Carolina gneiss. Hunter (1940, p. 98) was the first to use the term "alaskite" in the district. Alaskite was defined by Spurr (1900, p. 229-231) as a holocrystalline granular plutonic rock characterized by alkali feldspars and quartz with few or no mafic minerals. The alaskite and pegmatite in the Spruce Pine district generally consists of approximately 40 percent oligoclase, 25 percent quartz, 20 percent microcline (generally perthitic), and 15 percent muscovite. The most common accessory minerals are biotite, garnet, apatite, allanite, epidote, thulite, pyrite, and pyrrhotite. The total content of accessory minerals generally does not exceed 5 percent. Olson (1944, p. 23) reports several chemical analyses of alaskite, one of which is as follows: SiO<sub>2</sub> 74.9 percent, Al<sub>2</sub>O<sub>3</sub> 14.9, Fe<sub>2</sub>O<sub>3</sub> 0.33, CaO 1.0, K<sub>2</sub>O 4.7, Na<sub>2</sub>O 4.0, loss 0.2, for a total of 100.03 percent.

Large bodies or groups of bodies of alaskite occur in several parts of the district: the Brushy Creek-Gusher Knob area, Avery County; the Spruce Pine area, Mitchell County; the Kona area, Mitchell and Yancey Counties; the South Toe River Valley, Yancey County. The largest mass, between Spruce Pine and Chalk Mountain, is 4,000 feet wide and 2 miles long.

The average grain size of the alaskite is about 0.5 inch, but may vary widely within short distances. The margins of the bodies are generally finer grained than the interiors, most of the grains in the margins being less than 0.25 inch across. Scattered irregularly throughout the bodies are pegmatitic masses with grains greater than 0.5 inch across. Some of these pegmatitic masses change into finer grained alaskite across narrow zones only 2 inches wide. Other pegmatitic bodies have sharp contacts with enclosing alaskite, which suggests that perhaps they filled late fractures in the alaskite.

A foliation or layered appearance in some parts of the alaskite, especially near the margins of the larger bodies, is given by parallelism of mica flakes, streaks of quartz or feldspar, and parallel trains of small crystals of mica or garnet.

The central parts of most large bodies of alaskite are relatively free of inclusions of country rock but many parallel slabs of country rock occur locally near the margins of the bodies. Alaskite with many inclusions grades outward into layers of various types of schist and gneisses containing many parallel conformable sheets of alaskite and pegmatitic alaskite that range in thickness from a few feet to more than 100 feet. The tendency for concordance between alaskite and pegmatite and the host rocks is much more pronounced in the

schistose mica rocks than in the amphibole rocks and fine-grained mica gneisses.

Exposed bodies of pegmatitic alaskite number several thousand. At least 400 pegmatites have been exploited by mine workings and many others are exposed that are too small to mine or are barren of economically valuable minerals. The size of some pegmatites have been exaggerated on the geologic map in order to show them. They range in length from a few inches to 2,000 feet and in width from a few inches to 1,000 feet. Most of the mineral grains in pegmatite are larger than 0.5 inch across; rarely they exceed 15 feet across.

The bodies of pegmatitic alaskite form lenses, sills, dikes, and irregular masses in alaskite and in the metamorphic rocks. Some cut across the foliation and layering of the host rocks, others are partly or entirely conformable with the enclosing rocks. Pegmatites are most likely to be concordant in micaceous rocks, particularly the mica schists, and least likely to be concordant in the amphibole rocks.

Most of the pegmatites are distributed unevenly in a northeastward trending area 25 miles long and 10 miles wide. They are abundant in the western and northern parts of the Spruce Pine district, but are very sparse southeast of the large alaskite bodies in the southeastern part of the district (pl. 1).

The alaskite and pegmatitic alaskite are essentially massive rocks that are more resistant to mechanical breakdown than the enclosing layered metamorphic rocks. Consequently, they may stand out from the surrounding rocks as mounds or even as cliffs on the hillsides.

Chemical weathering results in the formation of clay minerals from the feldspars; thus, white clayey soils are developed which contain fragments of quartz and muscovite and perhaps some perthitic microcline that has weathered more slowly than plagioclase. Iron stains are common at places, caused by alteration of ferromagnesian minerals in the alaskite or pebmatite or of included fragments of country rock. Soils developed from alaskite or pegmatite generally can be distinguished by color and by the size of the fragments of quartz and muscovite; the fragments are coarser in the soils derived from pegmatite.

Other details of the alaskite and pegmatitic alaskite, including age determinations and a discussion of zoning in the pegmatites, are given in recent reports by Maurice (1940), Kesler and Olson (1942), Olson (1944), Cameron, Jahns, McNair, and Page (1949), Parker (1953), Carr and Kulp (1957), and Eckelmann and Kulp (1957).

### BASALTIC AND DIABASIC ROCKS

Thin dikes and sills of black diabase and basalt, too small to be shown on the map, sharply cut the alaskite, pegmatite, and the layered metamorphic rocks. The rock of the dikes and sills consists chiefly

of labradorite, augite, and olivine; some of the augite and olivine is altered to serpentine. The textures are fine grained to porphyritic and diabasic. The porphyritic rocks have phenocrysts of augite and olivine. Small thin veins of zeolite, calcite, and iron sulfide cut the dikes and sills. Chilled margins are common.

The dikes and sills are most abundant in the northeast part of the district, chiefly north and east of Plumtree. Dikes cut pegmatite at the Elk, Freel Vance, and Slippery Elm mines along Plumtree Creek and at the Puncheon Camp mine along Puncheon Camp Creek. A sill about 6 feet thick is exposed at altitude 3,220 feet in Fall Branch between Middle Elk and Elk Ridge. The dike at the Slippery Elm mine is 10 inches thick; it strikes N. 30° W. and dips 75° NE. The dike is diabasic with zoned plagioclase laths as long as 1 mm with interstitial grains of augite 0.6 mm across. The dike at the Elk mine is a basalt porphyry with phenocrysts of olivine and augite (0.3 mm across) and laths of plagioclase (1 mm long and 0.1 mm wide) in a fine-grained groundmass consisting of equal amounts of augite and plagioclase. Corroded phenocrysts comprise 25 percent of the rock. Plagioclase phenocrysts are three times as abundant as those of augite and olivine.

These rocks may be related to the Triassic volcanic rocks of the central Piedmont in North Carolina.

### STRUCTURAL GEOLOGY

The rocks of the district have been folded into a southwestward-plunging asymmetrical synclinorium about 20 miles wide that has its steeper limb on the northwest side. The central part of this major structure is occupied by micaceous and amphibolitic gneiss and schist and the various younger intrusive rocks. The micaceous and amphibolitic rocks are surrounded by the Cranberry granite on the northwest and the Henderson granite on the southeast (Keith, 1903, 1905, 1907). The northwest, northeast and east boundaries of this map are close to the contact of the Cranberry and Henderson granites of Keith. Eckelmann and Kulp (1956) have discussed these units and their relation to the micaceous and amphibolitic rocks of the Spruce Pine district.

The synclinorium in this district has three major structural zones. The northwestern and western parts of the district are characterized by steeply inclined isoclinal folds. In the northwest, the folds have been overturned to the northwest, their strike is northeast and they dip from 45° SE. to nearly vertical. In the west, around Burnsville, the trend of the folds becomes southerly and the dip is vertical. The rocks of this zone are varied, with the amphibolitic rocks predominating in the northeast and the micaceous rocks predominating in the southwest.

The eastern and southeastern parts of the district are characterized by micaceous rocks, including much schist, of variable strike and low dip, generally less than 30°. The variability of the strike and the low dip makes the local structures more obvious in this area than on the northwest side of the district. The northeastern end of the synclinorium is in the northeastern part of the district where the steeply inclined northwest limb of the synclinorium merges with the relatively flat-lying southeast limb.

The central part of the synclinorium is occupied by structurally complex rocks that have been intruded by large bodies of alaskite and many pegmatites. This central belt has a width of 4 to 5 miles and extends from Plumtree, Avery County, southwestward to the Sevenmile Ridge area, Yancey County.

An extensive shear zone extends from Penland, northwest of Spruce Pine, through Estatoe to Gillespie Gap, south of Spruce Pine. The shear zone is several hundred feet wide in many places. In it the gneisses and schists have been brecciated, sheared, and hydrothermally altered to rocks containing abundant chlorite and iron sulfides. The zone is traceable between outcrops by the abundance of flakes of green chlorite in the soil. Excellent exposures occur along U.S. Highway 19E at Liberty Hill Church near Estatoe.

### ECONOMIC GEOLOGY

The major mineral products of the district are from the alaskite and associated pegmatites. The chief products are feldspar, muscovite (sheet and scrap), and kaolin. These commodities make up over 90 percent of the total mineral production of the district. Amounts of other pegmatite minerals, including quartz, beryl, tantalite-columbite, rare-earth, and uranium minerals, are an extremely small part of the mineral resources of the district. Actual or potential products from rocks other than the alaskite and its pegmatites are olivine, vermiculite, asbestos, talc, chromium and nickel, soapstone, mica schist, garnet, kyanite, dolomite marble, and construction materials.

Index maps of the district showing the names and locations of many mica and feldspar mines are included in reports by Kesler and Olson (1942) and Olson (1944).

### FELDSPAR

Feldspar for glass, ceramics, and enamel glaze has been the chief product of many mines in alaskite and associated pegmatites. The economic geology of feldspar in the district has been described by Olson (1944, p. 41–50).

The commercial feldspars include both perthitic microcline (potash spar) and plagioclase ranging in composition from albite (soda spar)

to calcic oligoclase (soda lime spar). Microcline and plagioclase commonly are intermixed, but either feldspar may predominate in some parts of the pegmatite. Plagioclase is generally more abundant than microcline except in a few bodies. Microcline, however, tends to occur in coarser masses and to be segregated into units that can be mined selectively. Larger parts of these units may have graphic intergrowths with quartz (corduroy spar). Massive quartz cores or pods generally accompany microcline-rich units; in some pegmatites microcline forms large euhedral crystals in massive quartz.

Pegmatites containing large amounts of microcline are thick (25 to 150 feet) and occur in or near the belts of abundant alaskite extending along the southeast side of the district from near Ingalls through Spruce Pine to the Crabtree Creek area. Units of blocky plagioclase are less common and smaller than units of microcline and are more likely to occur in mica pegmatites some distance from the large bodies of alaskite. The feldspar recovered in these pegmatites ranges from about 15 to 30 percent of the rock mined, although in recent years the percentage appears to have declined somewhat. The recovery of plagioclase from mine-run rock is as much as 50 percent lower than that of potassium feldspar.

The common impurities in commercial feldspar are quartz, kaolin, muscovite, and biotite. They are not objectionable if not too abundant because they introduce no additional elements to the ground product, although first-quality feldspar must contain less than 5 percent of quartz. Abundant garnet and biotite are especially objectionable because they introduce iron, which may discolor the final product. These minerals must be cobbed out or removed electromagnetically in milling.

Prior to 1940 all of the feldspar was mined from pegmatites by hand, but since 1940 the commercial production of feldspar has been revolutionized by feldspar flotation. Alaskite has replaced pegmatite almost completely as a source of raw material because (a) the bodies of alaskite are larger than the pegmatites and are thus able to supply the large quantities of material needed for milling, (b) the compositional and mineralogical uniformity are greater in alaskite than pegmatite, making the alaskite a more desirable flotation feed. Thus, bodies of alaskite containing at least a million tons can probably provide a mill with feed of sufficient quality to justify the cost of a mill. Alaskite for flotation must also have a low content of iron and clay minerals; excessive iron discolors the final product and clay minerals interfere with flotation. The flotation mills are versatile and can be set to yield any of the three main products for glass, pottery, or enamel glaze according to rigid specifications, along with byproducts of scrap mica and quartz sand (Lutjen, 1953).

In the Spruce Pine district the reserves of feldspar in the parts of alaskite bodies within 50 feet of the surface recoverable by flotation exceed 200 million tons.

Of the byproducts, scrap mica has a market—although the demand for this product is insufficient to use up the supply created by the flotation of alaskite. Scrap-mica users still prefer the product separated from the clay of the weathered bodies of alaskite because the books do not powder when delaminated. As the supply of scrap mica from weathered deposits is reduced, users will be forced to seek new sources of supply: the flotation of alaskite appears to be the best future source of scrap mica. The reserves of scrap mica exceed 38 million tons.

The byproduct quartz sand is of very high purity, but up to 1953 had not been used in quantity. Under present economic conditions (1959), this product does not compete successfully with other commercial sources of silica. The product makes an excellent construction sand, especially for concrete and plaster aggregates; small quantities are sold for this locally. Reserves exceed 80 million tons.

### SCRAP MICA

Scrap mica is used in wall paper, paint, and lubricants, as filler and dusting powder for rubber products, and as backing for rolled asphalt roofing to prevent sticking. The geology and economic aspects of scrap mica deposits of the Spruce Pine and other districts of North Carolina have been discussed in detail by Broadhurst and Hash (1953).

The five major sources of scrap mica in the district, listed in their present order of commercial importance, are (1) hydraulic mining of weathered alaskite and pegmatite, (2) recovery as a byproduct from the beneficiation of kaolin, (3) recovery as a byproduct of feldspar flotation, (4) recovery as a byproduct of sheet mica and feldspar mining, and (5) mining of the mica-rich parts of quartz-mica veins (locally called "schist") on Tempa Mountain. The biotite schists of Tempa and Hanging Rock Mountains also have been mined for mica to grind.

Sources 1 and 2, which involve the mining of both weathered alaskite and of pegmatite, have been most important. The reserves of scrap mica in deposits mined primarily for this material (source 1) are estimated by Broadhurst and Hash (1953, p. 15) to be 25 million tons of ore containing 12 to 18 percent mica. The reserves of scrap mica obtainable from the mining of kaolin (source 2) are about 7.5 million tons from kaolin reserves of about 50 million tons having an average mica-content of 15 percent (Hunter, 1940, p. 102; Parker, 1946).

Scrap mica recoverable as a byproduct of feldspar flotation (source 3) is in excess of 38 million tons and is the largest demonstrated reserve of scrap mica in the district. This scrap mica product is currently deemed somewhat inferior to that of the other sources, chiefly because the books are thick and break into powder when delaminated. Thus, this product is not satisfactory for some uses where thin small flakes of mica are needed, but where powdered mica is desired, it is adequate. The mica product of the flotation mills will be used more widely as the scrap mica from other sources disappears from the market.

Scrap mica as a byproduct of the sheet mica industry (source 4) is clearly a small supply dependent on the rate of production of sheet mica. The quartz-mica veins (source 5) probably furnish a smaller supply and a higher cost product than other sources.

### SHEET MICA

The Spruce Pine district has supplied about half of the sheet muscovite produced in the United States. Most of the mica is used by the electrical industry as insulating material. Jahns and Lancaster (1950) described comprehensively the properties affecting the value of mica (cleavage, hardness, structural imperfections, color, staining, electric properties), and the grading, classification, preparation and marketing of mica. Kesler and Olson (1942), Olson (1944), and Parker (1953) described the geology of mica deposits, and the properties and the economics of mica in the Spruce Pine district.

In the Spruce Pine district, thick books of mica may be pale red to red brown (ruby mica), light brown (rum mica), dark browngreen to light green brown (water colored), and various shades of green. In thin films, however, all these micas are colorless. Certain colors predominate in different parts of the district, although some mica of each color may be found in each part of the district. The area around Plumtree is characterized by the greatest variety of colors of mica. Mica from the pegmatites in the areas of large bodies of alaskite near Ingalls, Spruce Pine, and Crabtree Creek is generally green, brown-green, or green-brown. In areas north, northwest, and southwest of the alaskite belt, light-brown and red-brown mica predominate. Still farther out from the areas of alaskite, pale-red mica predominates, accompanied by some light-brown mica and virtually no green mica. Within pegmatites, green mica is commonly associated with massive units of quartz or units rich in perthitic microcline; pale red mica is commonest in microcline-poor pegmatites that have calcic oligoclase. Some pegmatites contain micas of two colors, but each color is restricted to a different part of the body.

Mineral stains decrease the value of the mica from about half of the mines in the district and are a serious defect in some mica in about one-fifth of the deposits. Mica from pegmatites in alaskite is commonly, but not invariably, stained. The proportion of stained mica from the different mines ranges from near zero to 100 percent. Specks may be abundant at the center of the book and scarce or absent at the edges; the reverse occurrence is rare. Both clear and stained mica may be found in the same book.

Many structural defects of mica decrease both the amount and size of trimmed sheets recoverable. These defects include "A" and wedge structures, intergrowth of adjacent sheets (tied, locky, or gummy books), ruling, reeves, bends, and hair cracks. Most "A" and wedgeshaped mica is green. Pale red mica with "A" structure is relatively rare, but is found in a few mines in the southwestern part of the district. "A" mica is most abundant in microcline-rich pegmatites in areas of abundant alaskite in the southeastern part of the district. Where "A" mica occurs at the margins of masses of quartz, as it commonly does, the point of the "A" generally projects into the feldspar, away from the quartz. Garnet is associated more commonly with green "A" mica than with flat red or brown mica. Other structural defects appear to be common in all parts of the district and books entirely free from all defects are rare.

To yield trimmed sheet crude books of mica must be at least 2 inches in diameter; the average commercial book is about 5 inches, but books as much as 8 inches in diameter are fairly common. Most books are one-fifth to one-half as thick as they are wide, although a few are nearly as thick as wide. Blocks weighing 50 to 100 pounds are rare. The proportion of large books does not seem to vary geographically or with the type of deposits, but data are not available for a definite conclusion. In general, "A" mica is thought to constitute a relatively large proportion of the large blocks weighing more than 100 pounds.

Muscovite books of a size and quality to yield sheet mica generally are confined to pegmatites that consist predominantly of mediumgrained plagioclase and quartz, or to zones of this composition within more complex pegmatites. Rock containing small to moderate amounts of microcline intermixed with plagioclase and quartz also may be rich in sheet mica, but pegmatites or pegmatite zones in which microcline is the predominant feldspar contain little but green "A" muscovite. Books of mica are rare in graphic-granite. Flat palered and light-brown mica of high quality is mostly associated with calcic oligoclase. Muscovite associated with quartz-rich pegmatite is generally in small books or flakes ("burr"), or in wedge "A" blocks. The mutual exclusion of important amounts of coarse microcline and books of muscovite in the same rock mass is the basis for the common division of commercially important pegmatites into mica or feldspar deposits.

Muscovite is distributed through nearly all parts of every pegmatite, but concentrations of commercially valuable muscovite are restricted to certain parts of a pegmatite body.

In disseminated deposits, the concentration of commercial mica is uneven and no systematic disposition of the richer portions has been found. These deposits generally occur in relatively thin lenses or sills of pegmatite in metamorphic rocks, although a few are in pegmatite bodies in alaskite. The mica of the disseminated deposits is generally flat and clear. Nearly half of the deposits mined in the district are of this type.

Books of mica are concentrated in the wall zone of two-thirds of the zoned pegmatites, or about one-third of all pegmatites mined. This relation prevails in pegmatites with feldspathic or quartz cores. Mica may be about evenly distributed throughout the wall zone or most abundant near the contact with another zone. The hanging-wall zone is substantially more productive than the footwall zone of many pegmatites. Most of these pegmatites are enclosed by metamorphic rocks. The mica is generally flat and pale red, brown, or brown green. Concentrations of lower-grade mica in the core margins accompany deposits of good-quality mica in the wall zone.

The commercial mica of many of the pegmatites is especially abundant in rather well-defined narrow elongate portions of unzoned pegmatites or particular zones within the body. These relations are most common in the large tabular and lenticular pegmatites. Such concentrations are referred to locally as shoots, columns, veins, streaks, chimneys. (The term "vein" also may be used to describe a narrow pegmatite body.) Books of mica are not necessarily restricted to these shoots, although commercial mica may be rare in other parts of the pegmatite. Most of the shoots plunge southward obliquely down dip of the pegmatites at moderate to low angles. Mining experience indicates that some large pegmatites have two or more parallel shoots.

Many shoots, especially those in disseminated and wall-zone deposits, seem to be localized by, and to follow, outward rolls or sharp bends of the pegmatite contacts. They occur under archlike parts of the hanging wall and along the crests of elongate lenses or pipes, where the dip is lower and the pegmatite thicker. Shoots in steeply dipping bodies generally plunge parallel to rolls or irregularities in the contact between pegmatite and enclosing rocks. Some shoots,

however, are independent of such rolls. Other shoots widen or thicken on structural terraces. Some shoots are so straight that they suggest secondary fracture control but the mineral constituents of the shoot grade outward into those of the rest of the pegmatite.

The following types of mica deposits are not abundant in the district: deposits in zones intermediate between the wall and core zones; deposits as fringes of mica along the margins of quartz cores; deposits in core zones, and deposits controlled by fractures.

The reserves of sheet mica in the district probably at least equal the production to date. Many bodies of pegmatite have not been explored, many have been partly mined, and a few are exhausted. Book mica generally constitutes 2-6 percent of the rock mined in pegmatites. Commercial sheet mica commonly is 5 percent of the minerun books.

### KAOLIN

Kaolin for high-quality ceramic products has been produced in the district for many years.

The kaolin deposits, composed predominantly of kaolinite with some halloysite, were derived residually by the chemical weathering of alaskite and associated pegmatite. The clay minerals are mixed with altered plagioclase, perthitic microcline and practically unaltered quartz and muscovite.

The depth of kaolinization ranges from 40 to 100 feet in some commercial deposits. All the commercial deposits underlie older terrace levels of master streams and their larger tributaries at altitudes of 2,550 to 2,750 feet above sea level. The tops of the deposits are from 65 to 345 feet above the nearest master stream. The bottoms of the deposits generally extend to stream level, although the bottoms of deposits near Lunday lie 200 feet above the local drainage, because the North Toe River has deeply incised the old erosion surface.

Selective mining is employed in the clay deposits to bypass inclusions of undesirable materials. Small inclusions of mica schist can be removed easily in washing, but large inclusions of mica gneiss and amphibole rocks must be omitted from the mill feed because of the danger of excessive contamination, especially by iron. Fine-grained stained mica and garnet crystals, that weather to specks of iron and manganese oxides, are most undesirable impurities; little of them can be removed in the normal processes of clay beneficiation. Kaolin is beneficiated by a complex series of processes. The details of modern mining and refining methods are described by Hubbell (1943).

Detailed descriptions of the major kaolin deposits and their reserves are included in a report by Parker (1946). Parker's report also included earlier estimates of reserves by Hunter (1940). They conclude that the district contains about 50 million tons of crude kaolin of which about 15 percent is the maximum recovery for the final washed product.

### OTHER COMMODITIES

### QUARTZ

Exclusive of the quartz collected as a byproduct of feldspar flotation, some quartz of high quality has been produced in the district from pegmatites with cores or pods of massive, smoky, gray, or white quartz. Microcline and green "A" mica are associated with the quartz but ordinarily can be cobbed out to yield a silica product of high purity. Transportation costs are too high to make the Spruce Pine area a source of high-purity silica except for the most specialized uses. The silica for the glass of the reflecting telescope on Mt. Palomar, Calif., is reported to have come from the core of the pegmatite at the Chestnut Flat mine.

### BERYL

Most of the beryl occurs along the south and southwest sides of the district. The most notable mines include the Biggerstaff Branch and Poteat mines in Mitchell County, the Old Black mine in Avery County, and the Ray mine in Yancey County. The beryl forms golden or pale-green well-formed prismatic crystals ranging in size from a fraction of an inch to about 3 inches in diamter. It is generally found near the cores of bodies of pegmatites of moderate size that contain considerable amounts of perthitic microcline. Production has been negligible, and no regular production appears possible.

Green beryl (aquamarine and emerald) was mined commercially many years ago at the Grassy Creek emerald mine and the Grindstaff emerald mine on Crabtree Mountain in Mitchell County. The Ray mine in Yancey County has also produced some golden beryl and aquamarine. Further details are given by Kunz (1907).

### TANTALITE-COLUMBITE

Tantalite-columbite and associated samarskite occur as accessory minerals, generally in feldspar-rich parts of the pegmatites in the Spruce Pine and Crabtree Creek areas and in several other places, notably the Randolph mine north of Burnsville. The minerals occur with perthitic microcline at the McKinney mine in upper Crabtree Creek valley. Other localities include the Deake, Pink, and Wiseman mines in Mitchell County and the Ray mine in Yancey County. Minor quantities have been sold as a byproduct of feldspar mining, but reserves are small.

### RARE-EARTH MINERALS

Minerals that contain rare-earth metals, mostly cerium, include allanite and monazite. Allanite, a minor constituent of pagmatites, generally is associated with calcic oligoclase. It is most common on the periphery of the mining belt. Allanite is noncommercial even as a byproduct.

Monazite is rare in the district, but occurs in accessory amounts especially in the pegmatites of the Green Mountain area. No placer deposits are known.

### URANIUM MINERALS

Traces of uraninite, uranophane, gummite, torbernite, autunite, clarkeite, euxenite, and samarskite are common in many pegmatites. Localities known for their radioactive minerals include the Deake. Flat Rock, McKinney, Pink, and Wiseman mines in Mitchell County and the Carolina Mineral Co. No. 20 and Ray mines in Yancey County. During 1950, an unsuccessful attempt was made by private interests to operate the Fanny Gouge mine as a source of uranium. Commercial possibilities for uranium production from the pegmatites of the district are poor.

### OLIVINE

Olivine of refractory grades of two types—with more or less than 45 percent of MgO-occurs in commercial quantities in at least five of the dunite masses in the district. The most important source has been the Day Book deposit about 4 miles north of Burnsville in Yancey County, but even here careful mining is needed to meet refractory standards of purity because of contamination by bronzite, talc, and serpentine in the granular olivine.

The Spruce Pine district has large reserves of olivine which may be of greater economic value in the future. Details of the olivine deposits of the district have been described by Hunter (1941), who estimated the reserves to be over 7 million tons of granular olivine and 30 million tons of serpentinized olivine.

### VERMICULITE

Vermiculite is associated with many dunite bodies in the district, and has been produced commerically at Frank, Avery County, and at Day Book and other nearby bodies in Yancey County. It is generally found along the contact between dunite and pegmatite (Kulp and Brobst, 1954). It is also generally associated with talc and anthophyllite asbestos in the zone of contact metamorphism. The details of vermiculite production and its economics, as well as descriptions of individual deposits, are reported by Hunter and Mattocks (1936) and Murdock and Hunter (1946). Compared with the industrial demand, the reserves of vermiculite in the district are very small.

### ASBESTOS

Asbestos, mostly anthophyllite, has been mined on a small scale in several deposits in the district, particularly in the Frank body of dunite in Avery County where mining has been carried on intermittently for many years, and at the Blue Rock deposit in Yancey County. Its occurrence is generally restricted to contacts between the dunite and the country rock, or to zones of contact metamorphism between pegmatite and dunite, and along shear zones within the dunite. Anthophyllite asbestos also makes up a small part of many soapstone deposits. Chrysotile asbestos is reported by Hunter (1941, p. 57) from the White Oak Creek area 1 mile southeast of Bakersville. Because of the limited occurrence of the dunite bodies with which the asbestos is associated, the reserves in this district are probably not great.

### TALC

Small amounts of talc could be produced as a byproduct of olivine mining. The talc occurs in veins and masses along fractures within the body of dunite and along the peripheral zones of the body. Much of the talc in soapstone bodies is too impure to be of commercial value.

### CHROMIUM AND NICKEL

The chromite veins and lenses in the dunites of the Spruce Pine district are common enough to have interested commercial venture. Hunter, Murdock, and MacCarthy (1942) concluded that the deposits are so small and of such low grade that they are workable only with abnormally high prices or as a byproduct of possible future production of olivine.

Nickel is only an accessory element in the minerals of the dunites, and commercial possibilities are poor.

### SOAPSTONE

About 8.5 million tons of soapstone is available in the altered dunite bodies of the district, but most of it is of low quality. Some of the better material is used locally in construction.

### MICA SCHIST

Muscovite schist has been mined at many places in small pits on Tempa Mountain 1 mile east of Spruce Pine. The schist contains coarse flakes of muscovite with minor amounts of biotite, quartz, and feldspar. Quartz veins ranging from thin stringers to masses up to 7 feet thick cut the schist. Near the veins the schist is coarser and contains some small books of muscovite. Much of the scrap mica produced has come from near these quartz veins. This mica has been ground by the dry method.

The chlorite-biotite schists of the altered shear zones on Tempa Mountain and Hanging Rock Mountain have been mined in opencuts averaging 100 feet in length and 30 feet in depth. The impure product, which includes some actinolite, has been ground dry and sold for use in manufacture of asphalt roofing.

Most of the mica schists do not make good sources for scrap mica because they contain impurities. The mica delaminates poorly in comparison to the scrap mica derived from the alaskite and pegmatite bodies.

### GARNET

Although there are large amounts of garnet in some of the schists and gneisses of the district, they are probably of little commercial value because most of the grains of garnet are small, impure, and contain incipient fractures. These characteristics are poor for the maximum efficiency of garnet as an abrasive, which is the chief commercial use of this mineral.

The only commercial production of garnet recorded in the district was as a byproduct of kyanite mining on the slopes of Bowlens Pyramid southeast of Burnsville in Yancey County during the early 1940's.

The rocks richest in garnet are altered facies of the hornblende rocks on the northeast slope of Fawn Mountain, along upper Blue Rock Branch in Yancey County, and on a ridge crest 1.2 miles S. 84° E. of the highway bridge across the South Toe River in Newdale, Yancey County. Commercial garnet production has not been attempted at any of these locations.

### KYANITE

Blue kyanite is a common accessory mineral in many mica gneisses and schists in the Spruce Pine district. It is especially abundant in a belt about 2 miles wide extending southwestward from near Bandana in Mitchell County through Pigpen Bluff to the Black Mountains in Yancey County. Distribution of kyanite in this belt is irregular, but local concentrations of kyanite comprise 40 percent of the rock. The estimates of kyanite reserves are based on the assumptions that kyanite-bearing rocks average 15 percent of kyanite. Assuming a minable depth of 50 feet, a reserve on the order of 40 million tons is estimated.

The only commercial kyanite mine in the district was operated from 1934 to 1944 on the slopes of Bowlens Pyramid 2 miles southeast of Burnsville by the Yancey Cyanite Co. (also known as Celo Mines, Inc., and Mas-Celo-Mines). Mica gneiss containing 10 to 15 percent of disseminated kyanite needles and blades up to 4 inches long was mined in a large quarry and underground mine. A detailed investigation of the deposit was made by Chute (1944). Other kyanite prospects in the area were described by Stuckey (1932).

### DOLOMITE MARBLE

Hunter and Gildersleeve (1946, p. 28) have estimated conservatively that 500,000 tons of high-grade dolomite might be available from the Bandana deposit, Mitchell County. This estimate is based on an outcrop width of 25 feet, a downward extension of 100 feet and a length of 2,000 feet along the strike.

### CONSTRUCTION MATERIALS

Various bodies of gneiss in the district have been quarried for local use as building stone and road metal. Hornblende and mica gneiss have been used in masonry for walls, houses, and public buildings. Quarrying is intermittent; work is done as the need arises.

Many of the best rock quarries are simply enlargements of road cuts, such as the quarry a quarter of a mile north of Penland, and the quarry along the road between Kona and Rebels Creek in Mitchell County. Both of these are quarries in layered hornblende rocks. Another quarry in hornblende gneiss lies 500 feet north of the crossing of U.S. Highway 19E over Crabtree Creek. Ellipsoidal masses of chlorite-biotite schist from the shear zone on Tempa Mountain have been used in the construction of a business building in Spruce Pine.

Waste rock from mine dumps, consisting mostly of feldspar and quartz with some mica, is used as road metal in driveways, secondary roads, and access roads. The large dumps of the McKinney mine on the west fork of Crabtree Creek have supplied many tons of this material.

Soapstone, obtainable from deposits scattered over the district, has been used locally for house piers, chimneys, fireplaces, and grave stones. The variable mineralogic composition of the material would make continuous mining of a product of uniform quality most difficult.

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